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E. Marley, R. Shepherd, E. S. Fulkerson, L.
James, J. Emig, D. Norman

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Ultra Fast X-ray Streak Camera for TIM Based Platforms^{a)*}

E. V. Marley,^{1,2,b} R. Shepherd,¹ S. Fulkerson,¹ L. James,¹ J. Emig,¹ D. Norman¹

¹Physics and Life Science, Lawrence Livermore National Laboratory, M.S. L-490, Livermore, California 94550

²University of California Davis, One Shields Avenue, Davis, CA 95616

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Ultra fast x-ray streak cameras are a staple for time resolved x-ray measurements. There is a need for a ten inch manipulator (TIM) based streak camera that can be fielded in a newer large scale laser facility. The LLNL ultra fast streak camera's drive electronics have been upgraded and redesigned to fit inside a TIM tube. The camera also has a new user interface that allows for remote control and data acquisition. The system has been outfitted with a new sensor package that gives the user more operational awareness and control.

I. Introduction

Streaked X-ray data has been a staple in characterizing plasmas. Since the advent of short pulse lasers, there have been few x-ray streak cameras^{1,2,3} with adequate temporal resolution to sufficiently resolve dynamic behavior resulting from sub-picosecond laser matter interactions. Most short pulse laser matter experiments utilizing these streak cameras have been performed at small (< 1J) to medium (< 200J) facilities. However with large, short pulse lasers now coming online (Omega EP, NIF-ARC, Orion,...) Ten Inch Manipulator (TIM) based ultra fast X-ray streak cameras are required.

We have adopted the LLNL sub-picosecond X-ray streak camera for operation in a TIM tube. This article discusses the numerous changes and upgrades to the LLNL streak camera system that allow it to be operated as a TIM based diagnostic in a new laser facility.

II. The LLNL TREX Streak Camera

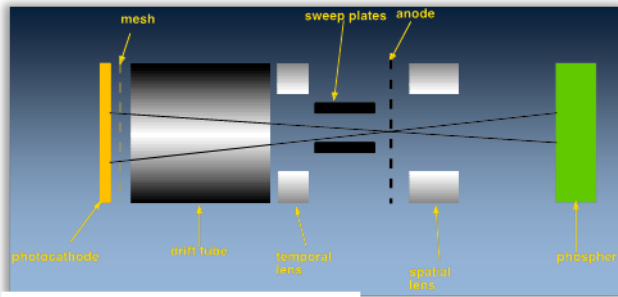


FIG. 1 LLNL Streak Camera Layout

A. Electron Optics

The layout for the LLNL streak camera is given in fig. 1. The LLNL streak camera differs from most commercially available streak cameras in several ways. The most notable difference is the separation of the temporal and spatial lenses. The two planer lenses are oriented orthogonally to produce a two-dimensional image at the focal plane. This separation mitigates the curvature characteristic with the use of a cylindrical electron optic, which couples the spatial and temporal axes. SIMION was used to model the electric fields created in the camera body. SIMION is a software program for doing charged

particles optics simulations. Mainly, it calculates 2D/3D electrostatic and certain magnetic fields and calculates the trajectories of charged particles through those fields⁴. The spatial lens is equivalent to a parallel plate electron focusing optic.

B. Pulsed Photo-Cathode

Another, subtler, difference is that the LLNL camera utilizes a pulse charged photo-cathode. The sources of time dispersion in an x-ray streak camera are given in the following:

$$\Delta t_{inst} = \left[(\Delta t_{phys})^2 + (\Delta t_{tech})^2 \right]^{1/2} \quad (1)$$

Where Δt_{tech} is the dispersion due to the slit width and sweep speed ($\Delta t_{phys} = \Delta x_{slit} v$, where v is the sweep speed) and Δt_{phys} is given by:

$$(\Delta t_{phys})^2 = \Delta t_c^2 + \Delta t_k^2 + \Delta t_L^2 \quad (2)$$

Where Δt_c is the transit time dispersion due to Coulomb repulsion, Δt_k is the transit time in the cathode-mesh region, and Δt_L is the transit time dispersion in the electron focusing optics region. The most dominant of these terms is Δt_k and it is given by⁵:

$$\Delta t \approx \frac{3 \times 10^{-8} [(E_0 + \Delta k T/2)^{1/2} - (E_0 - \Delta k T/2)^{1/2}]}{E_{field}} \quad (3)$$

where E_0 is the kinetic energy of the electrons in eV, $\Delta k T$ is the full width at half-maximum (FWHM) energy spread of the electron energy distribution in eV, and E_{field} is the electric field strength of the accelerating field in V/cm. Commercially available cameras typically have an extraction field of approximately 10 keV/cm. By using a gold-coated silicon substrate for the photo-cathode and pulse charging it the LLNL streak camera can achieve field strengths exceeding 250 keV/cm. This stronger extraction field allows the LLNL to achieve time resolutions of ~ 500 fs.

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^{b)}Author to whom correspondence should be addressed: marley2@llnl.gov.

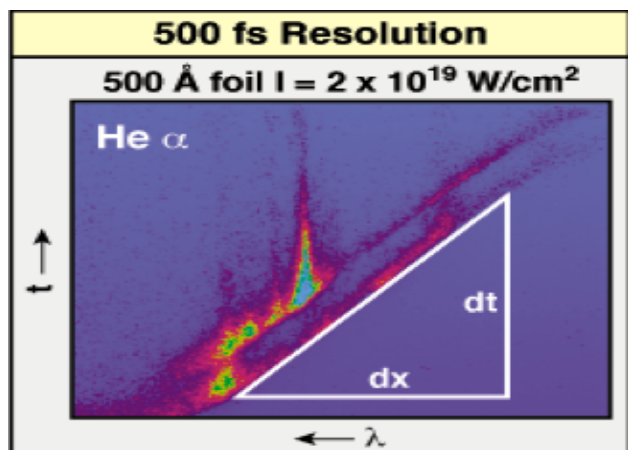


FIG. 2 Sample Streak Camera Data

C. Output

The LLNL ultrafast x-ray streak camera has been used prior to the adaptation to a TIM based geometry. In previous utilizations, the streak camera was placed on the focal axis of a dual crystal, von Hamos spectrometer. To successfully place the streak camera slit on the focal axis of the crystals, the entire streak camera (including readout) was placed in the vacuum. The compact nature of the streak camera made this possible. The target used in this experiment was a 500 thick aluminum foil illuminated with a 150 fs, 200 mJ laser pulse at $\sim 1 \times 10^{19} \text{ W/cm}^2$. Figure 2 shows an example of these data collected with the LLNL streak camera⁶. Each sloped line is x-rays reflected from an RAP diffraction crystal. The slope is due to the differing transit times of the x-rays reflected along the length of each individual crystal. The two crystals have slightly different radii and hence the x-rays have different transit times to the streak camera. The sloped nature of the output has the added advantage of providing a convenient calibration of the sweep speed.

III. Adaptation to TIM Tube

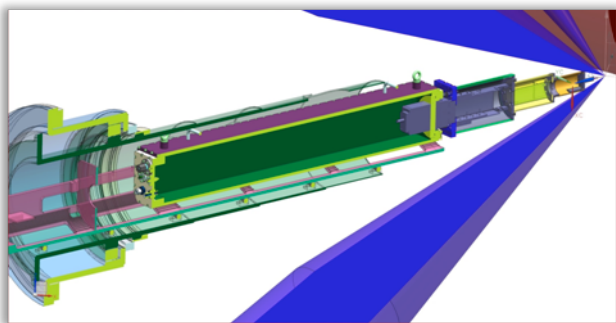


FIG. 3 LLNL Streak Camera and Airbox in TIM Tube

A. Mechanical Fitting

The LLNL streak camera does not have a self-contained vacuum vessel. The camera is mounted to the end flange of the TIM tube and sits in the chamber vacuum and a seal is made between the streak camera phosphor and the TIM flange. The image intensifier and CCD readout is attached to the phosphor output, inside the airbox, with a mechanical fixture. The streak camera sits inside a 0.7mm thick mu-metal shroud that minimizes the effects of external magnetic fields on the electron bunch in the drift tube. The outer shell is a 5mm thick aluminum cover to block stray light.

B. Drive Electronics

The LLNL streak camera drive electronics have been redesigned to fit entirely within an airbox that will be contained in the TIM tube. The airbox will house the sweep and cathode fast avalanche transistor pulsers as well as the power supplies for the electron optics, the sweep and steering bias, and the image intensifier. The power supply control chassis is rack mounted in the laser bay and controlled by a remote desktop.

The cathode and sweep pulsers are capable of delivering 15 kV pulses with a ~ 150 ps rise time. While not as important for the cathode functionality, this fast rise time is necessary for maximum temporal resolution of the sweep in a linear regime.

A time domain reflectometer (TDR) was used to measure the through time delay of the sweep and cathode circuits to reduce the amount of shots necessary to time in the streak camera.

C. Readout and Display

The information contained in the electron bunch is converted to an optical format via a phosphor. This is coupled a Photek image intensifier with a fiber optic faceplate. The image intensifier is then imaged with a Spectral Instruments SI 1000 CCD camera. The CCD camera control and readout PC is a rack-mounted unit that is controlled with a remote desktop PC.

IV. Computer Control and Interface



FIG. 4 LLNL Streak Camera Control Software Front Panel

A. Control Electronics

The LLNL created LabView control software is used to monitor and control all aspects of the streak camera's operation. The software is installed on a desktop PC that is located in the control room and communicates with the laser bay rack mounted power supply control chassis and the CCD control PC via fiber Ethernet.

The output voltage for all power supplies can be set using the control software. Once the electron optics have been "aligned" and the sweep and cathode have been correctly timed the voltage settings can be saved to a set-up file and recalled at anytime. The voltage settings can also be password protected to prevent any unwanted or accidental changes to the cameras operating parameters. The voltages are also monitored in real time and can be saved on a shot to shot basis.

The software also gives a visual indicator of the interlock chain so that the systems ready status can be determined at a glance.

B. Monitors and Sensors

In order to protect the streak camera the power supply control chassis has voltage and current monitors on six of the eight controllable power supplies. These monitors are used for

software detection of an over current fault caused by break down in the camera. The fault levels can be set for each individual power supply. Upon detection of a fault the software will disable the high voltage interlock and notify the user to the faults location.

The airbox itself is host to a number of environmental sensors that give the user information about the conditions inside the airbox. The temperature, humidity, and pressure are all monitored and will trigger alarms if the conditions inside the airbox fall outside of the user defined parameters. The coolant flow to the CCD camera is also monitored and must be present to make up the CCD power interlock.

C. Data Collection and Storage

This CCD readout is integrated into the LabView control software. The raw image can be saved along with the voltages sent to the camera from each of the powers supplies. The image can also be processed within the control software using an LLNL developed IDL routine to give the spectral data and the time history of the captured event.

VI. Conclusion

The LLNL sub-picosecond x-ray streak camera has been adapted to operate in a TIM based platform of a large laser facility. The drive electronics have been upgraded and reconfigured to fit inside an airbox designed for a TIM tube. The new user interface allows for camera control and data acquisition to be done from a remote desktop PC. The UI also allows for the user to check the system status with several voltage, current, and environmental monitors. A thorough end-to-end test is currently being conducted on the TIM based version of the streak camera as of the time of this writing. The first application will occur at the Orion facility at the Atomic Weapons Establishment later this year.

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⁴<http://simion.com/info/simion.html>

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⁶Ronnie Shepherd et al, "Time resolved spectroscopy of ultrashort pulse laser generated x rays using von H[a-acute]mos crystal spectroscopy", *Rev. Sci. Instrum.* 75, 3765 (2004), DOI:10.1063/1.1791751

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